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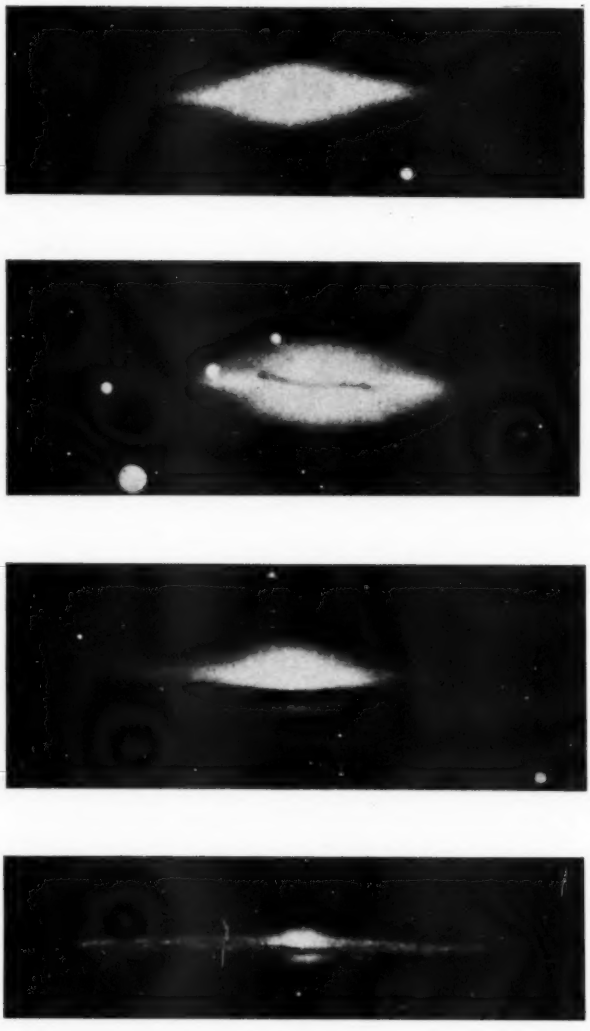

PLATE X

Figures 3, (top), 4, 5, 6 (bottom)

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OF CANADA

VOL. XVIII OCTOBER No. 8

THE O-TYPE STARS AND THEIR RELATION TO THE STELLAR EVOLUTIONARY SEQUENCE*

By J. S. PLASKETT

INTRODUCTION

The choice of the above subject for the presidential address to Section III of the Royal Society was governed by two main reasons. First an investigation of the radial velocities and other phenomena of all the O-type stars within reach at Victoria has occupied most of my time for the past three years, the results are now in press, and it seemed useful to present here a summary of the most important conclusions reached and their bearing on present day ideas of the course of stellar evolution. Second the subject is sufficiently comprehensive to include all the sciences represented in Section III for as we shall see, mathematics, physics and chemistry have been required to an almost equal degree with astronomy in the development of the accepted theory of stellar evolution.

The astronomical material available for attacking this problem is relatively meagre and incomplete. The scantiness of our information about the stars is due to their enormous numbers, the feebleness of their light, the minuteness of their apparent motions, and their almost inconceivable distances. Hence there is available only partial and scattered knowledge about two or three thousand of the brightest from among a thousand million stars and even then

*This paper is an amplification of the presidential address to Section III of the Royal Society of Canada given at Quebec, May 21, 1924.

the obvious limitations of distance, size and temperature make any detailed examination, such as is possible in laboratory investigations, entirely out of the question. The attainment of additional astronomical data is such a slow and laborious process that were it not for the aid of the sister sciences to fill in the unavoidable gaps, the problem would have been almost hopeless of solution. That such a beautiful and apparently complete theory, which I shall now attempt briefly to sketch and show the peculiar place of the O-type stars therein, has been developed is a tribute to the resourcefulness and ingenuity of the human mind.

Evolution of the Nebulae

Without further preface, therefore, let us proceed to outline the probable course of development of the stellar universe. In all sciences it is necessary to start with some original postulates or primal substance, and in astronomy it is necessary to assume the existence of enormous quantities of matter of unknown origin, widely scattered over space in vast clouds of finely divided and probably ultimately gaseous material of almost inconceivable tenuity. These clouds by internal gravitational action would slowly aggregate into approximately globular form and any initial rotation, produced by initial motions or irregular distribution would inevitably increase on condensation, by reason of the conservation of angular momentum. The physical and mathematical treatment of the subsequent development, we owe to the genius of Jeans, who has given us a beautiful picture of the probable evolution of these enormous globes of gas or meteoric dust of density about one million billionth of our atmosphere and yet containing sufficient material to produce thousands or prehaps millions of suns.

Jeans' mathematical treatment of the subsequent process has shown that the increasing rotational velocity resulting from condensation would first produce a spheroidal form. However, in such a highly compressible nebula, the equatorial bulge even for moderate rotations becomes more pronounced and at a certain critical speed develops a sharp edge as shown in Figs. 1 and 2. Further increase of speed consequent upon continuing contraction cannot be compensated by any further adjustment of figure and the

resultant of the action of the centrifugal forces, the molecular interactions or viscosity, and the increasing angular velocity of the inner part will cause an outer ring of matter to appear to be thrown off, expanding as it rotates.

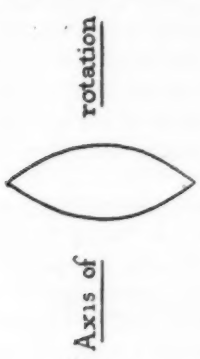

Fig. 1

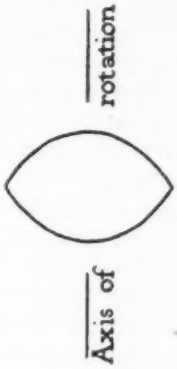

Fig. 2

Mathematical analysis here becomes uncertain, but fortunately we can supplement it by observation and show nebulae actually photographed, apparently illustrating successive steps in the process of evolution. Figs. 3 to 6 (Plate X) show photographs of nebulae as arranged by Jeans in probable order of development. Fig. 3 is an observed example of the lenticular forms mathematically developed in Figs. 1 and 2. Fig. 4 shows an example which may represent, by the bright and dark equatorial appearances, the throwing off of a ring of matter. This is confirmed by Fig. 5 in which the emitted ring has cooled down and is obscuring the light of the nucleus. This nebula has been spectroscopically shown to be in relatively rapid rotation thus further confirming the theory. Finally there can be no doubt that Fig. 6 is a photograph of the familiar spiral nebula seen edge on, thus completing the chain of development.

The expanding ring of gaseous matter is unstable, cannot remain continuous and breaks up into condensations. Very few examples of such concentric rings of condensation are known, the most conspicuous example being N.G.C. 7217, while in the overwhelming majority the condensations lie along two spiral curves, appearing to

branch out from opposite sides of the central nucleus. Although there are many difficulties in the mathematical treatment, the concentric rings seem to correspond to the ideal case where the nebula is isolated in space, while the spiral form results from the tidal action of neighbouring nebulae. Such tidal action, whether small or great, will tend to localize the ejection of matter to two opposite points of the equatorial edge from which the condensations appear to issue and stream off in a spiral curve. The physical reasons for the equiangular spiral form of the nebular arms are uncertain but the observational evidence admits of no doubt that they are almost universally present.

The proper motions of the condensations in the spiral arms of several nebulae measured by Van Maanen, make it very probable that this motion is outward along the arms, proportional to the distance from the central nucleus, and corresponds to a rotation period on the average of nearly 100,000 years. Jeans has very recently discussed these observed motions mathematically, and has shown that they may be produced by a central force inversely proportional to the square root of the distance, markedly different from the force of gravitation. This curious result may of course be due to uncertainties in the very small motions observed and too much stress should not be placed on the reality of this peculiar law of force.

Jeans has, however, established, based on the probable physical conditions of the matter in the spiral arms, how far apart the condensations should be and this evidently gives us a clue to the distance of the spirals, confirmed by independent methods. An analogous analysis shows that the average mass of one of these condensations will be of the order of 10^{34} grams, a mass comparable with the average star, the sun being 2×10^{33} grams. He further shows that the density of the central nebular nucleus is about 4 times 10^{-17} grams per cubic centimetre. By terrestrial standards this density is incredibly low but nevertheless will correspond to about a million molecules per cubic centimetre and a mean free path of 2000 km. It easily follows from these results that the mass of the spirals is of the order of 100,000 times and may be in some cases millions of times the sun.

We may hence consider, with reasonable probability, that each of the thousands of spiral nebulae in the sky is thus projecting into space condensations or nuclei of extremely tenuous matter of the same order of mass as the stars and which we must believe eventually develop into the stars. It appears that these nuclei, owing to their very low density soon become non-luminous but that the inevitable subsequent though slow gravitational condensation and the aggregation of adjacent nebular matter will cause an increase in the mass, density, temperature and rotational velocity. Jeans has traced, by further mathematical treatment, the subsequent development of those nuclei with sufficient mass and angular velocity, and has shown that they may develop into rotating ellipsods, pear shaped figures and final division by fission, forming double stars. Although the analysis is not complete, astronomical observation shows its high probability as at least one star in four or five is a close double and in the very massive B and O-types the proportion approaches one-half. Further evidence is afforded by certain eclipsing variables which are shown by analysis of their light curves to be almost in contact and hence probably recently divided.

Physical Conditions in the Stars

Having thus sketched the probable origin of the aggregations of matter from which the stars originate, it is now in order to attempt to trace their subsequent development and the steps in their evolution. The mathematical and physical treatment of the conditions at the surface and in the interior of the stars we owe to another famous English astronomer, Eddington. Every member of this section is doubtless aware of the usual explanation of why the stars are hot and is familiar with the old idea of the maintenance of solar and stellar heat by contraction. Eddington has, however, placed these ideas on a much sounder basis and has removed many of the difficulties by taking account of the previously unrecognized factor of radiation pressure, aetherial pressure as he calls it, and has developed a beautiful and complete theory of the conditions in the interior of the stars.

It is impossible to go into the details of this theory and it must

suffice to state that it takes account of the gravitational pressure inward opposed partly by molecular motions, the elasticity of the gas, and partly by radiation pressure. The radiation outward is obstructed by the opacity and the dissociation of the atoms at the enormous temperatures in the interior has also to be allowed for. Taking account of these factors, he has calculated the conditions of density and temperature in the interior of an average giant star, which are given in the accompanying table, while in very massive stars the central temperatures may reach as high as 20,000,000 degrees. At these high temperatures, radiation pressure becomes a

Mass=1.5 Sun: Density=0.002: Type F7: Temp.=7500°K

Distances from centre	Density	Temperature
0	0.1085	4,650,000°K
.145	.0678	3,980,000
.290	.0215	2,710,000
.435	.00503	1,670,000
.58	.00100	974,000
.725	.000149	517,000
.87	.0000093	207,000
1.00	.000000	

large proportion of the total pressure and the opacity also becomes high on account of the exceedingly short wave length of the radiant energy corresponding to soft X-rays. Eddington has calculated that a layer of gas of the density of the terrestrial atmosphere and only 6 inches thick would absorb 95 per cent of this radiation.

The importance of mathematical physics in obtaining a picture of the conditions in the interior of a star, forever inaccessible to direct observation, has been clearly shown by Eddington. He assumes a physicist on a cloud-bound planet, who can know nothing of the stars, setting to work to calculate from laboratory data only the relative proportions of aetherial and molecular pressure in globes of gas of various masses. This calculation, given in the accompanying table, does not depend in any way on astronomical data and shows that radiation pressure is insignificant for masses below 10^{33} grams and overpowering beyond 10^{35} grams.

Gaseous Globes of Various Masses; Sun=2×10^{33} grams.

Mass of Globe	Radiation Pressure	Molecular Pressure
10^{30} grams	0.00000016	0.99999984
10^{31}	.000016	.999984
10^{32}	.0016	.9984
10^{33}	.106	.894
10^{34}	.570	.430
10^{35}	.850	.150
10^{36}	.951	.049
10^{37}	.984	.016
10^{38}	.9951	.0049
10^{39}	.9984	.0016
10^{40}	.99951	.00049

If the veil of cloud is now removed the physicist on looking up into the skies sees a thousand million globes of gas, the stars, practically all of mass between 10^{33} and 10^{35} grams. The lightest known star is just below 10^{33} and the heaviest, an O-type, 6°1309, discovered by me is 1.5 times, 10^{35} grams. For globes much below 10^{33} grams the temperature will not rise high enough for visibility, while beyond 10^{35} grams the radiation pressure becomes so nearly equal to the gravitational pull as to produce instability. It is of interest to note that the average mass obtained by this calculation for the stars is identical with the mass of the nebular condensations calculated by Jeans.

It has been further shown by Eddington that as long as the star remains relatively diffuse so that the gaseous material obeys the ordinary gas laws, the total brightness remains nearly constant and is a function of the mass only between the limits of visibility at a temperature about 3000°, when the star is an enormously distended globe of mean density of the order of a millionth of water on the one hand, to a temperature of some 20000° and a density about a tenth of water on the other. This and the previous theoretical results are practically confirmed by astronomical observation. It should be mentioned, however, that the astronomical data generally antedated the theoretical, and it seems possible that the trend

of the theoretical development may have been partially guided by astronomical results.

Astronomical Theories of Stellar Evolution

It is now time to consider more particularly the part played by astronomy in the development of the theory of stellar evolution.

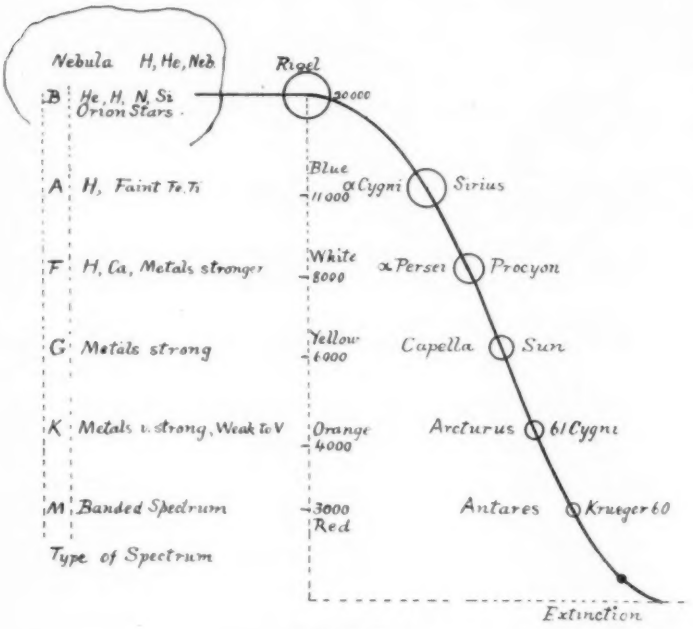

Figure 7

Astronomers by painstakingly accurate and long continued observations have accumulated data concerning the apparent and absolute brightness, the tangential and radial motions, the distance and dimensions, the temperature and other physical conditions, and the sequence of spectra in a limited number of stars. By masterly

generalization they have combined this scattered information into a comprehensive theory of stellar evolution. After the application of spectroscopy to the stars, the first theory to be developed which held nearly undisputed sway until about ten years ago, postulated the condensation of the stars from the gaseous and not the spiral nebula. The initial stage then was an intensely hot and tenuous blue star at the maximum stellar temperature, increasing density, decreasing volume and diminishing luminosity through the white, yellow and red stars to extinction, as diagrammatically represented in a general way in Fig. 7. The English astronomer Lockyer and his associates were practically the only dissentients from this view, strongly insisting upon both an ascending and descending temperature scale. His ideas were evidently in advance of the times and there were in addition some difficulties in his theory to account for its non-acceptance. It remained for Hertzsprung and Russell, chiefly the latter, who has been the principal agent in converting astronomers to the new view, to formulate and substantiate the "giant" and "dwarf", the ascending and descending scale theory of stellar evolution.

According to Russell, these globes of gas of various masses between 10^{33} and 10^{35} grams, probably formed from the spiral nebulae in the manner described by Jeans and developing according to the physical laws formulated by Eddington, would eventually come, after aeons of time, to visibility as deep red stars of low density and large volume. We have the positive evidence of the existence of such enormously distended globes, such "giant" stars, in the measured dimensions of Betelgeuse and Antares, some three hundred million miles in diameter and of a mean density about the thousandth of an atmosphere. Condensation and increase of density and temperature continue and we have the red stars changing to orange like Arcturus, to yellow like Capella, to white like Alpha Persei, and to blue like Vega, Rigel and the other bright stars in Orion. Only the more massive of the stars, about ten times the solar mass, can reach the brightness and temperature, 15000°—2000°, of the stars in Orion. Stars of mass two or three times the sun can only reach the white stage, the sun itself was probably

never hotter than 7000°, while stars of mass much less than the sun cannot rise much beyond the red stage and some indeed may never come to visibility.

All the stars in the stage of ascending temperature are called "giants", the term referring not to mass but to the great volume due to the low density of these bodies. The maximum surface temper-

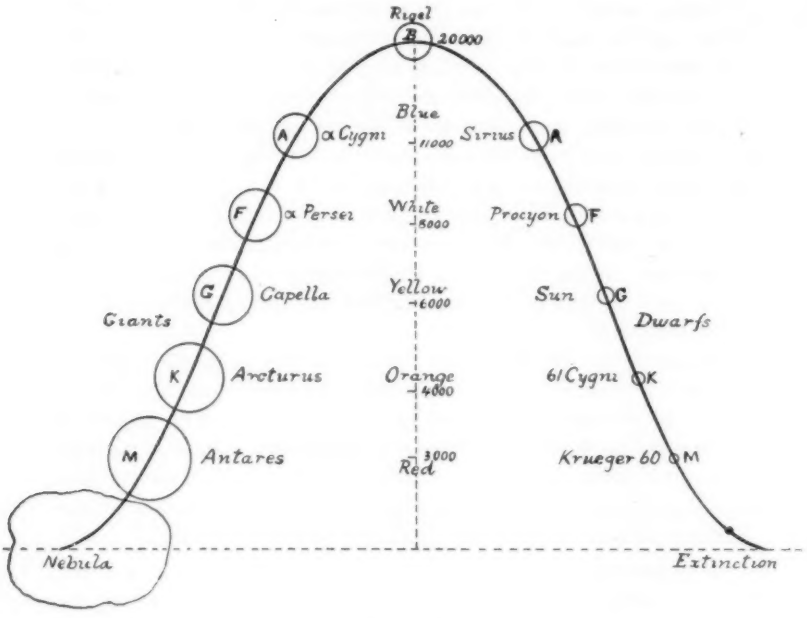

Figure 8

ature reached in this stage of development depends, as previously indicated, upon the mass and seems to be attained when the density reaches about one-tenth that of water. At this point it had hitherto been assumed that the ordinary gas laws begin to fail and continuing condensation can only result in decreasing temperature and luminosity. The stars now called "dwarfs" will pass in the reverse order

from blue through white, yellow, orange and red to extinction, our sun being a dwarf yellow star. A graphical representation of the stages through which a fairly massive star may pass in its development according to the giant and dwarf hypothesis is given in Fig. 8.

A paper read by Eddington at the March meeting of the Royal Astronomical Society makes it appear now, however, as if the dwarf stage of this theory may require modification. He apparently establishes theoretically and confirms it by observational data from double stars, Cepheids, and eclipsing variables, that even in the dwarf stage with a density several times that of water the stars still obey the gas laws. This unexpected behaviour is reasonably explained by the loss of the outer rings of electrons from the atoms of the elements owing to the tremendous temperatures in the interiors of the stars. The volume of the atom is hence reduced approximately a hundred thousand fold and the enormously closer packing possible obviously permits the gas laws to be obeyed even in the densest dwarfs. How much change this revolutionary paper will entail in the dwarf stage of the evolutionary scheme is not yet apparent but there seems no doubt that considerable modification will be required. I may be pardoned for mentioning that one of the principal observational supports of this new development was obtained from the dimensions of eclipsing variables determined by me at Victoria some three years ago.

The Position of O-Type Stars in the Evolutionary Sequence

The results above mentioned do not appear, however, to affect the place of the O-type stars in the evolutionary scheme. This remarkable group of stars is very limited in number, forming less than one-tenth of one per cent of those whose spectral type has been determined, and they have always been considered exceptional in their physical and spectral characteristics. They may be divided into two distinct though allied sub-classes, the emission O-type, Wolf Rayet, stars, whose spectra are uniquely characterized by broad bright bands with no absorption and the absorption O-type stars with spectra containing absorption lines and occasional narrow emission lines. The elements present are the same in both classes

and consist principally of hydrogen and helium and of ionized helium, carbon, nitrogen, oxygen and silicon. A third sub-class may perhaps properly be included, the planetary nebulae whose central nuclear stars are always emission or absorption O-types.

The presence of lines or bands in the spectra of this group due to the ionized atoms of the principal non-metallic elements is practically peculiar to this group, indicates clearly the exceptional position in the spectral sequence and the extreme temperature, considerably higher than any other spectral class. While the O-type stars have for many years been generally considered as probably a continuation of the spectral and evolutionary sequence beyond the B-type, Orion stars, there has been some evidence pointing to a smaller absolute magnitude, total brightness, for the O than the B-type, directly contradicting this idea. However, a careful analysis by H. H. Plaskett two years ago unmistakeably showed their continuous progression in spectral characteristics and temperature beyond the B's while the present investigation clearly proves their progression in mass and luminosity and places them at the head of the evolutionary sequence as undoubtedly the hottest, brightest and most massive of the stars.

It will be of advantage to briefly summarize in turn some of the results obtained from this investigation with respect to the masses, motions, distances, distribution and luminosity of the O-type stars, with the application of these data in the evolutionary theory, and to discuss finally the relations of the three sub-classes above described.

Mass—It has been shown previously from double star data that the average mass apparently increases with temperature. Yellow G-type stars like the sun, temperature 5000° – 6000°, average about the solar mass; white F-type stars like Alpha Persei and Procyon, temperature 8000° – 10000°, have two or three times the sun's mass; blue-white A-type s ars like Vega and Sirius, temperature 10000°—12000°, have four or five times the solar mass; and the blue B-type stars, such as Bellatrix and Rigel with temperatures around 15000° average about ten times the mass of the sun. The present investigation has shown that this progression in mass has continued in the much hotter O's with temperatures variously estimated from 20000° to 30000°. From orbital data of several O-type spectroscopic

binaries it seems certain that they are much more massive than the B's, ranging probably between 10 and 80 times the solar mass, with an average value about 40. The most striking example is the double system 6°1309 with minimum masses of 75 and 63 times the sun for the two components. These great masses for the O-type stars with the necessarily higher temperatures, which are both theoretically predicted and spectrally substantiated, undoubtedly place this remarkable group at the apex of the evolutionary sequence, to which only such very massive stars can attain. The fact that there are twenty times as many A-type as B-type stars and probably twenty times as many B-type as O-type stars tends to confirm this conclusion as rapid decrease of numbers with increase of mass is probable. No stars of greater mass or higher temperature than the O's are known and it seems necessary to assume that the evolution beyond them must subsequently follow a course of decreasing temperature and luminosity.

Motions—The O-type stars are exceptional in their motions as compared with the progression in velocities of the other spectral types. The residual radial velocities of the more common types are in kilometres per sec. M=17, K=17, G=15, F=14, A=11, B=6.5. If the same progression were followed, we should expect the O's to be only 4 or 5 km. but the present investigation gives a residual radial velocity of 25.5 km. for the absorption O-types. The emission O's are immeasurable while the planetaries have a velocity of 30 km. These stellar velocities are only exceeded by the red variables which have velocities of about 35 km. The discontinuity between the velocities of the O and B-types is unexplainable, unless it be assumed as depending in some manner on the distance for, as we shall see in the next paragraph, the O-type stars are four or five times the distance of the B's. The tangential or proper motions of the O's are exceedingly minute, only approached by another limited class, the N's, at the other end of the spectral sequence.

Distance and Distribution—The O-type stars are so remote from the sun that the ordinary trigonometrical method of determining distance is useless and recourse must be had to statistical methods of obtaining the average distance or mean parallax of the group.

By three different methods of combining the radial velocities and

proper motions of the O-type stars the mean parallax was computed as 0″.0011 corresponding to an average distance of 3000 light years, nearly five times as far away as the B's, seven or eight times the average distance of the other common types and only equalled in remoteness by the N's, deep red giant stars at the other extreme of stellar temperature and equally limited in numbers. In distribution the O-type stars are very closely confined to the plane of the galaxy, but fairly uniformly spaced in galactic longitude. They appear hence to form an annular disc in the plane of the milky way of an average radius of 3000 light years, entirely beyond the other naked-eye stars and, while the N-type stars are about the same average distance, they are not so closely limited to the galactic plane. It is perhaps worth while pointing out that the higher radial motions of the O's are what would be expected if the galaxy were considered as formed from an enormous spiral nebula with a law of motion varying with the distance from the centre similar to that found in the observed spirals. Another possible explanation may be supplied from Silberstein's recent discussion of space time curvature. According to this the Doppler displacement in the stars is the sum of two factors, the one due to the radial motion of the star and the other directly proportional to the distance of the star and inversely proportional to the radius of curvature of space time. For the O-type stars at 3000 light years this latter factor is about 10 km. thus reducing considerably the discrepancy between the O's and B's.

Luminosity—It will be of interest as illustrating modern astronomical methods to describe briefly the three methods employed in determining the luminosity, the total brightness or the absolute magnitude, as it is technically called, of the O-type stars. The "absolute magnitude" is defined as the apparent magnitude a star would have at a distance of 10 parsecs, 32.6 light years, remembering that the sun at that distance would be about 4.9 magnitude.

The first and probably the most reliable method of determining the absolute magnitude depends upon a simple application of the inverse square law to the apparent magnitude when the distance is known. For example if an O-type star at a distance of 1000 parsecs has an apparent magnitude of 4.9, the same as the sun at a distance of 10 parsecs, it is obviously 100^2 or 10000 times as bright as the

sun and has an absolute magnitude of -5.1. Using by a similar method the average apparent magnitude with the mean parallax or average distance obtained above, the average absolute magnitude of the O-type stars is easily determined as -4 corresponding to a brightness 4000 times the sun. This is an average value and from various considerations the individual values have a range of about 3 magnitudes or between say 1000 and 15000 times the sun's brightness.

The second method is an application of Eddington's theoretical treatment of giant stars based on considerations of the radiant energy, opacity and average molecular weight of stars of known mass and gives an absolute magnitude of -1.9, 600 times the sun for a star of mass 10, and absolute magnitude —47, 8000 times the sun for star of mass 80. The average value is -3.7, 3000 times the brightness of the sun by this method, in fairly close agreement with the first.

The third method, partly theoretical, depends on data or estimates of mass, density and surface brightness for these stars, and the total brightness can obviously be simply calculated when these three factors are known. The mass has already been accepted as varying between 10 and 80 times the sun. The density, from data obtained from eclipsing variables, modified by consideration of the high radiation pressure in these tremendously hot and massive bodies, probably lies between the values of one-tenth and one-hundredth of the sun, likely nearer the lower value. The surface brightness can be calculated from radiation laws when the temperature is known, assumed in this case as 20000°, and has also been determined for stars of various types by several different methods by Russell. The two determinations agree fairly well in making the surface brightness of an O-type star -3.75 magnitudes, over 30 times brighter than the sun per unit area. For density one-tenth, the average brightness of stars 10 to 80 times the solar mass is about 2000 times the sun and for density one-hundredth nearly 10000 times the sun's brightness.

Combining all three methods, with the greatest weight to the first, gives the average luminosity of the O-type stars as 4000 times the sun, several times brighter than any other spectral class and again

confirming their exceptional position in the theory of stellar evolution.

Relations of the Sub-Classes—The spectra of the O-type stars has already been briefly described, its super-enhanced nature pointed out and the differences between the absorption and emission sub-classes referred to. All the information just discussed about mass, velocity, distance and luminosity refers only to the absorption O's as in the emission O's or Wolf Rayet stars no such data can be obtained owing to the breadth and mixing of the emission bands. The physical cause producing such wide bands in the Wolf Rayet stars is obscure as with the low order of pressure now accepted for stellar atmospheres, it is obviously impossible of explanation as a pressure effect. Previous attempts at the spectral investigation of these mysterious objects, the most puzzling in the sky, with the possible exception of the Novae, have not resulted in much advance and it seemed worth while, as a considerable number of spectra were obtained in the course of this investigation, to examine the relationships between them and the absorption O's.

Some advances appear to have been made by this analysis. The majority of the broad bands have been identified and shown to be analogous in constitution and state of ionization to the absorption O's. The Wolf Rayet stars observed have been arranged in order of excitation and shown to be generally similar in this respect also to the absorption O's. From the analysis of some transition examples between the two sub-classes it appears probable that the Wolf Rayet stars develop as a sort of side chain from the absorption stars, and apparently at any stage of the temperature sequence of the latter. The physical causes producing this change from absorption to wide emission are obscure but the apparently accidental development does not seem to be a function of the temperature. It is possible that mass may have something to do with it but unfortunately we know nothing of the mass of the Wolf Rayet stars, although the third sub-class, the planetary nebulae with O-type nuclei, appear to be even more massive than the absorption O's.

So long as one can keep an open mind on such a question, it is fascinating and perhaps useful to speculate on the effect of exceptional mass on the subsequent development of an absorption

O-type star. Radiation pressure approaches equality with the gravitational force for masses over 50 times the sun and it may be that the resulting instability is one of the causes of the eruption of emissive material eventually producing a Wolf Rayet star. From the transition examples observed, this emission appears to gradually blot out both the absorption and continuous spectrum until practically only the wide emission bands remain, which may account for the probably lower luminosity of the Wolf Rayet stars. When it is considered that the planetary nebulae are probably considerably more massive than the absorption O's, that their radial velocities are nearly the same and that their nuclei are always O-type stars, it does not seem unreasonable to assume that the surrounding nebulosity may have been produced by excessive radiation pressure "blowing out" the outer layers of the star. As a matter of fact Campbell's "hydrogen envelope" star 30°3639 appears almost like one caught midway in the process, an excellent transition example. It must not be forgotten, however, that these are speculations with little supporting evidence and many opposing phenomena. However, the possibility of such speculative support of the analogies in the three sub-classes, only adds to the evidence of their unique place in the evolutionary sequence.

Stationary Calcium and Sodium—Although apparently without direct bearing on the question of stellar evolution, another result of this investigation should be briefly referred to. In practically all absorption O-type and Wolf Rayet stars observed and in many of the "early" B's there appear in the spectrum sharp and narrow H and K lines of calcium and also wherever tested sharp and narrow D_1 and D_2 of sodium. The sharpness and the stationary position of these lines as contrasted with the diffuseness and the shifting position of the star lines unmistakably points to a practically stationary origin outside the stellar atmospheres. The only possible explanation seems to lie in the presence of very widely, almost universally, distributed but exceedingly tenuous clouds of matter throughout interstellar space; practically at rest with respect to the stellar system. All the stars are moving through these clouds with varying speeds but only the very high temperature stars such as the O's or early B's have sufficient exciting power to produce the sharp

calcium and sodium absorption lines. It may be added that such a stationary cloud has been suggested, perhaps not very seriously, as possibly forming a fixed reference system in space.

In conclusion it may, I think, be safely stated that sufficient evidence has been obtained from this investigation of the O-type stars to definitely place them at the apex of the evolutionary sequence, and to show the great interest and importance of this very limited class.

THE SYSTEM OF σ CYGNI

By F. HENROTEAU

THE spectrum of σ Cygni has been classified by the Harvard observers as B8p. It shows very sharp and narrow lines having the c characteristic shown by all pseudo-cepheids such as α Persei, γ Cygni, α Cygni, β Orionis and other stars. We have reasons to suspect that these stars have very small densities, very large absolute brightnesses and highly ionized atmospheres.

The stars of late class B having the c characteristic are very few; only two are given in a list of 300 stars of classes O and B whose parallaxes have been derived by Professors W. S. Adam- and A. H. Joy,[1] while only three are found in Bottlinger's catas logue[2] of 459 stars (giving their accurate colour indices).

The spectroscopic orbit of σ Cygni was determined by the writer in 1916 while at the Observatory of the University of Michigan[3] and the following elements have been obtained:

$$V = -3.80 \text{ km.}$$
$$P = 11.043 \pm 0.042 \text{ days}$$
$$e = 0.40 \pm 0.08$$
$$K = 1.98 \text{ km.} \pm 0.186 \text{ km.}$$
$$\omega = 119^\circ\ 6' \pm 14^\circ\ 46'$$
$$T = 9.27 \pm 0.34 \text{ days}$$
$$a \sin i = 275{,}700 \text{ km.}$$
$$\frac{m^3{}_1 \sin^3 i}{(m+m_1)^2} = 0.000{,}007\,\odot$$

There has been found some peculiarity in the behaviour of the Hϵ line but this need not be considered in the following deductions.

In 1920, Professor Guthnick, who had no knowledge of the existence of the star's orbit, found with his photo-electric cell that σ Cygni is slightly variable.[4] This is Professor Guthnick's report: "σ Cygni, a spectroscopic binary with still unknown period

[1] Mt. Wilson Contribution No. 262.
[2] Veröff. der Univ. Sternwarte zu Berlin-Babelsberg, Band III, Heft 4.
[3] Publ. of the Obs., Univ. of Michigan, Vol. III, p. 49.
[4] Astr. Nachr., Vol. 212, p. 167.

and of spectral class B8p, has been found to be variable. The amplitude of variation of magnitude is $0^m.05$ or more. The measures made to date indicate Algol type. The star was at or very near minimum brightness on October 11, 12, 13 and again on October 30, 31; it was of normal brightness on October 20, 21, 22, 28, 29."

From the character of the spectrum and elements of the orbit, σ Cygni could be classified among the cepheid variables. However, it would be an exceptional cepheid, having a period of about eleven days; such a length of period is usually found for stars of much more advanced spectral class, a typical example being ζ Geminorum (class Go, period 10-15 days, mean magnitude 3.9). Contrary to the rule in cepheids, no variation of aspect of spectral lines is found in σ Cygni.

The chances are that σ Cygni may be considered as of the Algol type, thus a real binary. This will lead to interesting results.

Professor Guthnick's observations indicate that the duration of the eclipse is two or three days.

At maximum the magnitude of σ Cygni is 4.28 and at minimum 4.33. For the corresponding brightnesses Pogson's formula gives 0.01542 and 0.01472, thus during eclipse obtaining a darkening of 0.00070. This shows, if the small body is dark, that the ratio of the surfaces of the two bodies is about 1/25, and so the ratio of the diameters 1/5 and of the volumes 1/125.

The duration of the eclipse being about one-fifth that of the revolution period, necessarily i, the inclination of the orbit, is approximately 90° and no appreciable error will be committed by supposing $\sin i = 1$. This gives:

$$a = 275{,}700 \text{ km.} \tag{1}$$

$$\frac{m_1^3}{(m+m_1)^2} = 0.000{,}007 \odot \tag{2}$$

which may be written:

$$m + m_1 = \sqrt{142857 m_1^3} \tag{3}$$

The semi-major axis of the orbit described by the secondary around the primary is

$$a' = a \times \frac{m+m_1}{m_1}.$$

The diameter of the primary is practically equal to the chord of the ellipse whose arc is described during 1/5 of the period, or if the sun's diameter 1,394,000 km. is taken as a unit, it may be considered to be $a' \times 10^{-6}$.

From general observations and theoretical considerations certain limits have been reached for the masses of the stars. The value of m is no doubt within the limits found in the following table or not far beyond. In this table, m and other corresponding elements of the system were obtained, starting from assumed values of m_1.

m_1	m	m/m_1	Diameter of primary	Density of primary	Diameter of secondary	Density of secondary
0.01	0.36	36	10.3	0.00033	2.1	0.00111
0.02	1.05	52	14.6	0.00033	2.9	0.00083
0.03	1.93	64	17.9	0.00033	3.6	0.00064
0.04	2.98	74	20.7	0.00033	4.1	0.00058
0.05	4.17	83	23.1	0.00033	4.6	0.00052
0.06	5.50	91	25.3	0.00033	5.1	0.00045
0.07	6.93	99	27.6	0.00033	5.5	0.00042
0.08	8.47	106	29.6	0.00033	5.9	0.00039
0.09	10.11	112	31.1	0.00033	6.2	0.00038
0.10	11.90	119	32.1	0.00033	6.4	0.00038
0.15	21.85	146	40.5	0.00033	8.1	0.00028
0.20	33.60	168	46.6	0.00033	9.3	0.00025

Eddington found that bodies of masses as small as m_1 would not be very bright; a body having a mass of 1/7 that of the sun could never attain 3000° centigrade, which is the lowest admissible temperature for the body to shine as a star. The secondary body would be more of the nature of a planet with a very tenuous atmosphere, a sort of enlarged Jupiter, perhaps the first indication of the existence of a planet attendant to a star other than our sun.

Knowing the diameter of σ Cygni, its parallax may be found by the formula given by Bottlinger,[2] which is

$$\log 1000\pi = 2.25 - 0.2m' + 2 \log (c_2/T) - \log \rho$$

where π is the parallax, m' the bolometric magnitude, c_2/T a value given in Bottlinger's catalogue, and ρ the diameter of the star, that of the sun being unity. In this case $m' = 3.70$ and $c_2/T = 1.21$.

It is found for $m_1 = 0.01$ $\pi = 0''.000664$

for $m_1 = 0.20$ $\pi = 0''.000008$

The co-ordinates of proper motion of σ Cygni given in Boss's catalogue are $\mu_\alpha = -0^s.0004$, $\mu\delta = -0''.006$ and the trigonometric parallax, as determined at the Allegheny Observatory, $-0''.001 \pm 0''.009$.

The present note leads to the following important conclusions:

1. The mean density of σ Cygni is about 0.0003, that of the sun being unity. This compares favourably with the densities 0.0006 and 0.0004 obtained by Shapley for the two components of β Lyrae.[1] It shows that a considerable difference of density exists between ordinary B stars (density 0.1) and this giant B star σ Cygni. The excessive contraction necessary to pass from a giant B9 to a dwarf B introduces difficulty in explaining stellar evolution.

2. Practically there is proof that in other stellar systems there are bodies having the nature of planets. Perhaps stars like our sun with several attendant planets, for instance β Orionis. This star which is of spectral class cB8 has a spectroscopic orbit similar to that of σ Cygni. According to J. S. Plaskett[2] its radial velocity curve presents variations of amplitude. This may be explained by the hypothesis that β Orionis possesses more than one planet, each forcing the central sun to undergo radial velocity oscillations, which combined give a curve of variable amplitude.

Dominion Observatory, Ottawa.
July 15, 1924.

[1]Astroph. Journal, Vol. 38, p. 169.
[2]Report of the Chief Astronomer, Dom. Obs., 1909, p. 224.

REMARKS CONCERNING CERTAIN GROUPS OF CEPHEIDS

By F. Henroteau

In a recent article (Bull. of the Astronomical Institutes of the Netherlands, vol. II, No. 56), studying the light-curves of several Cepheids of the region near Carinae, Professor Ejnar Hertzsprung concludes that there is no apparent relation between the mean magnitudes of these variables and their periods. The region of η Carinae apparently forms an immense star cloud, very conspicious and well delimited as one can see on the accompanying photograph which is a reproduction of one of the Franklin Adams charts. If all the stars of this region really form a cloud they ought to be at the same order of distance from us, and if this is the case, the period-luminisity law for Cepheid variation does not appear to be satisfied.

It seems very important to determine both visual (or photovisual) and photographic light-curves of Cepheids and so obtain their mean colour-indices. . If possible also we should determine the mean spectral classes of all the Cepheids; these are probably in close relation with their colour-indices. Most of the colour-indices of variables in star-clusters such as those of the Small Magellanic Cloud have not been determined (only estimated from theoretical considerations) and we are in urgent need of them. Perhaps Professor Hertzsprung would find interesting results if he determined the colour-indices of the Cepheids (more than two dozen of them in a rather small area of the sky) of the η Carinae Cloud.

The star clouds in the region of Sagittarius present a considerable analogy in appearance with the region of η Carinae. Here also there is a fairly large number of Cepheids and for most of them the spectral class is approximately known. These Cepheids (whose spectral classes are known) are classified in the following table in order of increasing visual magnitudes.

Star	Mean Visual magnitude	Spectral class	Logarithm of period
X Sagittarii	4.70	F6	+0.85
W Sagittarii	4.70	F5	+0.88
Y Sagittarii	6.20	F8	+0.76
U Aquilae	6.55	F7	+0.85
YZ Sagittarii	7.45	F9	+0.98
U Sagittarii	7.50	F8	+0.83
TT Aquilae	7.60	F9p	+1.14
WZ Sagittarii	8.15	G5	+1.34
SZ Aquilae	8.70	Gp	+1.23
RU Scuti	8.90	G5	+1.31
XX Sagittarii	8.95	G?	+0.81
Y Scuti	8.95	G5	+1.01
W Serpentis	9.05	G0	+1.15
Z Scuti	9.25	G0	+1.11
X Scuti	9.50	K?	+0.62
AI Scorpii	10.25	K?	?

Since the spectral class of a Cepheid varies, there exists some uncertainty concerning the mean spectral classes given here and a new and careful determination of them as well as of the corresponding colour-indices is needed. However when a graph is made from the above table taking the logarithms of the periods as abscissae and the visual magnitudes as ordinates one sees the probability of distribution in four groups of mean spectral classes F5, F8, G and K around the respective magnitudes 5, 7, 9 and 10. Thus in this case there appears to be a relation between luminosity and spectral class, but no definite relation between luminosity and period.

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A NEW THEORY OF GRAVITATION AND RADIATION*

By William Gore

I COME before you to-night with what will appear to many as a fantastic idea that the ether of space is full of holes and these holes give the explanation of universal gravitation and radiation. If the ether of space can be regarded as a frictionless fluid possessing mass and inertia—which observation shows it to possess—in a state of turbulence, which is generally considered to be the case, then it must be compressible and consequently contains within it void places. Otherwise the ether would be subjected to infinitely large compression forces which is absurd. The development of this idea leads to an explanation of the cause of universal gravitation; it gives an insight into the factors which have led up to the Theory of Relativity, it explains radiation as a surface phenomenon, gives a physical interpretation to Planck's Quantum and the Bohr atom.

Philosophically, the possibility of the existence of the void places in the ether is perfectly sound as they form the centres of a network of energy fibres of the columnar vortex type on which the universe is hung and by and along which unity, balance, equilibrium and communication is secured from one end of the universe to the other and in this respect the analogy to organic structures is obvious.

The theory as developed is partly mathematical and partly mechanical and the former can exist even if the latter be proved to be untenable.

Mechanical theories of the ether are usually short lived and there are none at the present time that receive any important consideration. Unlike Newton's law of gravitation or Einstein's Theory of Relativity, which are mathematical theories, a mechanical theory starting from simple, well understood principles has to explain everything not only within its provinces but also quite outside it. Thus, any complete mechanical scheme to explain the ether of

*Paper read before The Royal Astronomical Society of Canada, on March 25, 1924.

gravitation must also before its complete establishment explain electromagnetic phenomena and probably life itself. Mechanical theories are also more difficult to understand by the average individual. Thus the difficulties which any mechanical scheme of the universe has to face are enormous. In the present theory most phenomena are caught up within it. Some indication of the nature of electromagnetic phenomena is made but a complete rational scheme of this class of phenomena has not yet been established; but it is realized that such a rational scheme is necessary before the theory dealt with here can be fully established.

Unlike Einstein, we do not find it necessary to depart from the old fundamental conceptions of time and space and gravitational force in order to explain the new theory, nor do we find it neccessary to introduce the fifth dimension. We look out on the universe just in the way an engineer looks out upon his constructive problems, or as a normal astronomer looks out upon his. It is believed that the phenomena we witness in the universe depend upon the nature of the mechanical and kinematical qualities of the ether as well as upon those of the physical matter which appeals directly to our senses.

We postulate a quasi-elastic field of ether possessed of substantial properties to our reasoning faculties but which so far as experience has gone is devoid of the direct means of impressing itself upon our physical senses. Into this field are injected boundaried particles which we call physical matter which squeeze out the ether displacing it into the volume of the whole. As the particles and the field exist together, therefore each particle by reason of its influence on and in the field to all intents and purposes extends to the limit of the universe. We have a number of fundamental postulates as follows:

(1) Every particle of matter occupies a net space unto itself and has displaced an equal volume of ether which has spread out and strained the whole universe.

(2) When a particle moves a strain readjustment begins to take place in the ether which is propagated outwards continually at a finite velocity.

(3) The internal motions of the ether—which possesses mass

and inertia but not temperature—are in the form of stream lines to which the principle of the conservation of energy in the form enunciated by Daniel Bernouilli applies.

(4) The total internal energy of the ether both potential and kinetic is or may be at each point the same and equal to the product of half its specific mass into the square of the velocity of light.

(5) The ether is compressible and its internal motions in the form of vortices produce cavitations so that it becomes an ether of greatly extended surfaces containing probably square miles to the cubic centimetre.

(6) Except near physical matter which distorts the cavities, the cavities are in the form of straight tubes or hollow columnar vortices which extend from infinity to infinity in at least three co-ordinate directions closely packed together, the spinning being alternatively positive and negative. By analogy we may liken these tubes to the nerve system of a developed organism.

(7) Radiations take place along the surfaces of the void places by surface waves with a certain amount of cross communication.

(8) The distortion of the tubes by physical matter penetrating between them, resisted by gyrostatic action, is the cause of gravitation.

(9) The stream line velocity at the surface of the void places is that of light and the tubes are for ever irresistible to external force by physical matter. They are eternal.

(10) The striking of a tube by an electron takes away from the electron one quantum of energy and the reverse process adds one quantum of energy to the electron. All strikes are dead beat,—that is, there are no succeeding vibrations.

(11) The pattern or positions of the void places is quite simple and such that the only free paths for electrons are at such successive positions as to fit in with Bohr's atom.

(12) When an electron, while subjected to electromagnetic attraction by a proton, drops from one outer free path to an inner free path it encounters the void places repeatedly until a stable position is found. This process is reversible, giving rise to both emission and absorption spectra in accordance with the three fundamental series.

(13) The radiation or absorption of half of the energy change in an electron when falling or rising from one free path to another takes place in a definite interval of time and the frequency of the consequent radiation or absorption is dependent only upon the energy change.

(14) An electron is probably composed of the same fundamental substances as the ether subject to the same or similar internal motions and is in stable equilibrium with the ether and has a hollow core and probably is in the form of an anchor ring vortex. Thus, the specific mass of the ether may be the same as that of an electron.

(15) The nature of a proton has not been postulated except to the extent that it may be a condensation of the fundamental substance of which the electron and the ether are formed. This substance may be granular, the grains being possessed of polarity, moving in stream lines, giving rise to electromagnetic phenomena.

(16) Except in the case of direct hits giving out radiations the passage of physical matter in between the void places and vortices takes place without any resistance whatever, either frictional or wave motion.

We have now to look at some of the difficulties of the problem as disclosed by the statements of recognized authorities telling us what we may expect the ether to be like or not like.

Gravitation, the force or condition which appears to hold or draw all bodies in the universe together, has so far baffled all attempts to discover its innermost nature. Newton 250 years ago asked himself the question: "Why does an apple fall to the ground?" His answer was that the apple and the earth, like all bodies, are attracted to each other according to a definite law of mass and distance which he formulated in this way: Two bodies attract each other by a force passing through their centres of mass proportional to the product of their masses and inversely proportional to the square of their distances apart. This law with a slight exception has been sufficient for the explanation completely of the motions of the heavenly bodies as observed by astronomers. Newton sought for a mechanism which would convey this force of attraction from body to body but could not find one. In some way he attributed the attraction to an

external flux or pressure conveyed across an extended medium called the ether of space. Newton's explanation is as follows:

> It is inconceivable that brute matter should without the medium of something else which is not material operate on and affect other matter without material contact as it must do if gravity in the sense of Epicurus be essentially inherent in it. That gravitation should be innate, inherent and essential to matter so that one body may act upon another at a distance through a vacuum without the mediation of anything else by and through which their action or force may be conveyed from one to the other is to me so great an absurdity that I believe no man who has in philosophical matters a competent faculty of thinking can ever fall into it.

Newton did not consider this same medium as the transmission agent of light and other forms of radiation but it was so understood by his contemporaries, Hooke and Huyghens; the latter founded the undulatory theory of light which stands with certain additions, particularly those of Young and Fresnel, who demonstrated that light travelled in transverse waves and these were subject to interference, practically unassailed up to the present century.

During the time of Newton the astronomer Roemer discovered that light was propagated across space at a definite velocity. He made observations of the motions of the satellites of Jupiter and found that the times of the eclipses of the satellites by the planet's disc came earlier at certain seasons than at others corresponding very nearly with the yearly rotation of the earth about the sun and more nearly to the varying distance away of the planet Jupiter from the earth, and it became clear that differences of time observed were due to the differences in the time taken for the reflected light from the satellite to reach the observer. Thus, Roemer became the first relativitist and some relativitists regard him as the first astronomer. However, these observations disclosed an important property of the ether and its similarity in some respect to gross matter in that it conveyed signals of a certain kind at a perfectly definite speed demanding the recognition of the fact that the ether has elastic properties together with mass and inertia.

In the middle of the last century the experimental skill of Faraday and the mathematical genius of Maxwell disclosed some important particulars of the ether as the transmission agent of electro-magnetic radiations; and linked up this phenomena with that of light. Maxwell's description of the necessary qualities of

the ether are exceptionally clear and of essential value in this discussion. He said:

> We know that the ether transmits transverse vibrations to very great distances without sensible loss of energy by dissipation. A molecular medium moving under such conditions that a group of molecules once near together remain near each other during the whole motion may be capable of transmitting vibrations without much dissipation of energy, but if the motion be such that the group of molecules are not merely slightly altered in configuration but entirely broken up so that their component molecules pass into new types of grouping, then in the passage from one type of grouping to another the energy of regular vibrations will be frittered away into that of irregular agitations we call heat. We cannot therefore suppose the constitution of the ether to be like that of a gas in which the molecules are always in a state of irregular agitation, for such a medium a transverse undulation is reduced to less than one five hundredth of its amplitude in a single wave length. If the ether is molecular the grouping of the molecules must remain of the same type, the configuration of the groups being only slightly altered during the motion. If there is any motion of rotation it must be a rotation of very small portions of the medium, each about its own axis so that the medium must be broken up into a number of molecular vortices. We have as yet no data from which to determine the size or number of these vortices. We know, however, that the magnetic force in the region in the neighbourhood of a magnet is maintained as long as the steel retains its magnetism, and as we have no reason to believe that a steel magnet would lose all its magnetism by the mere lapse of time we conclude that the molecular vortices do not require a continued expenditure of work in order to maintain their motion, and that therefore this motion does not necessarily involve dissipation of energy. No theory of the constitution of the ether has yet been invented which will account for such a system of molecular vortices being maintained for an indefinite time without their energy being gradually dissipated into that irregular agitation of the medium which in ordinary media is called heat. Whatever the difficulties we may have in forming a consistent idea of the constitution of the ether, there can be no doubt that the inter-planetary and inter-stellar spaces are not empty but are occupied by a material substance or body which is certainly the largest and probably the most uniform body of which we have any knowledge.

Up to the present time the difficulties pointed out by Maxwell have not been surmounted and no ether has been postulated which possesses the necessary properties to transmit light waves the distances they are known to be transmitted.

Recently Einstein has again asked the question: "Why did Newton's apple fall to the ground?" and his answer is that the

apple, or the earth for that matter—it doesn't matter which—was just following its natural path in a distorted or curved field, but he keeps up the difficulties of the situation by demanding two ether fields instead of one for he says in discussing his general theory of relativity:

"Since, according to the present view, the elemental particles of matter are nothing other than condensations of the electro-magnetic fields so our present picture of the world recognizes two perfectly separate realities, viz., the ether of gravitation and electro-magnetic fields of space and matter. It would be a great advance if we could succeed in interpreting the gravitational field and the electro-magnetic field as a unified structure, then the contrast, ether and matter, would die away."

Einstein gives some further particulars of the ether as conceived by him:

"According to this theory of the ether the measurable qualities of the space-time continuum are different in the neighbourhood of the different space-time points and conditioned by the matter existing outside of the domain observed. This space-time variability of the relations of measuring rods and watches to one another and the fact that empty space in its physical qualities is not homogeneous has set aside the view that space is physically empty. With this has come the concept of the ether far different from the ether of the undulatory theory of light. The ether of the theory of general relativity is a medium free from all mechanical and kinematical quality. The principal difference between the ether of general relativity and the Lorentz ether consists in the fact that the status of general relativity ether is determined at every place by necessary connections with matter and the status of the ether in nearby places in the form of differential equation."

There is not much hope for the average man in understanding Einstein when Sir J. J. Thomson says that:

"It is the result of the highest achievement of human thought. The weak point is the great difficulty in expressing it. It would seem that no one can understand the new law of gravity without a thorough knowledge of the theory of invariants and the calculus of variation."

Einstein's success in predicting certain obscure natural phenomena, and the way in which his methods of looking into natural phenomena has appealed to scientific men, have given the theory of relativity wide publicity. Einstein, in his own peculiar way, has perceived, as Newton before him perceived, that the cause of gravitation lies in the modification of the ether by matter. But Einstein saw further, that any modification in the ether must take place across it as progressive phenomena when some part of the

system is in motion, and so change to some extent the gravitational field. But the cause of gravitation still remains hidden for Professor Eddington, the chief exponent of the theory of relativity in the English language, has made this clear when he says:

> In this discussion of the law of gravitation we have not reached any ultimate explanation of its cause. A certain connection between gravitational field and the measurement of space has been postulated but this throws no light on gravitation. The relativity theory is indifferent to hypothesis as to the nature of gravitation just as it is to hypotheses as to matter and light. It may not be an unobtainable hope that some day clearer knowledge of the processes of gravitation may be reached and the extreme generality and detachment of the relativity theory may be illuminated by the particular study of a precise mechanism.

And Sir Oliver Lodge, who so far has not shown any predilection for the relativity theory puts the present need very clearly when he writes:

> If we could understand the particle in terms of the medium of which it is composed and if we knew the structure of the rest of the medium also so as to account for the potential stress at every point that would be a splendid step . . . Time has to be associated with space. This can only be done by a velocity factor of some kind. But to arrive at an appropriate factor relativitists have not dived down into the ether as some one must ultimately dive and dissect out the intrinsic speed of its turbulence which is really the fundamental velocity in existence.

Thus, authority directs one to the essential need of a mechanical theory of the ether and matter. In postulates (1) and (2) we have the conditions required to nearly satisfy Newton's law of inverse squares and more nearly those of Einstein, but the study has been carried much farther than this and a mechanical scheme of the ether has been developed largely from a detailed study of the motions in ordinary water. It has been noticed that in water in motion there is a remarkable tendency for the formation of columnar vortices, frequently with persistent cavitation. This phenomena is clearly seen in the homely discharge of water from a bath tub or wash basin and on a larger scale within and in the vicinity of water works pumps and intakes and in the whirlpool below Niagara Falls where hollow columnar vortices many feet in depth readily form which are only damped out of existence by considerable friction. The same kind of phenomena exists in the atmosphere as shown by meteorological reports of cyclones, anti-cyclones and whirlwinds.

Thus, columnar vortices are the common accompaniment of fluids in motion in spite of the considerable friction which inevitably destroys them. The application of Bernouilli's theory leads to the conclusion that cavitation is inevitable in a frictionless—that is, a temperatureless—medium when in motion not subject to gravitational forces in its parts and there is no reason why in a medium indefinitely extended such cavities should not also be of indefinite length.

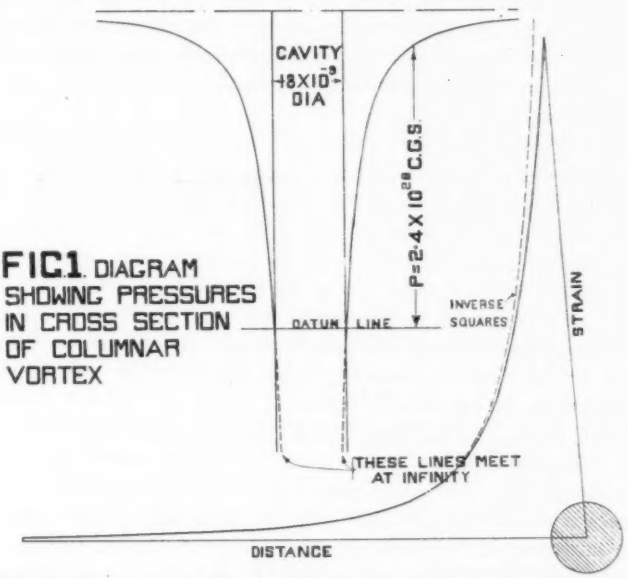

FIG.1. DIAGRAM SHOWING PRESSURES IN CROSS SECTION OF COLUMNAR VORTEX

FIG.2. DIAGRAM SHOWING STRAIN WITH DISTANCE IN GRAVITATIONAL FIELD

Figure 1 shows the pressure conditions in an ether columnar vortex. The sums of the potential and kinetic energy are a constant for every point in the section and the velocity of spin inversely proportional to the radial distance from the axis. At the surface of the cavity the pressure is zero and the whole of the energy is kinetic, while at an infinite distance the reverse is the case. The

speed of rotation at the free surface is probably that of light, but the average diameter of the column would not be much greater than three times that of the cavity. By assuming the cavity to be produced by the integrated contrifugal forces its size is determined in terms of the mass of the spinning substance, the bulk modulus of elasticity, and the velocity of spin and can be expressed in this way:

$$(\text{velocity at surface of cavity})^2 = \frac{1}{\frac{1}{2}(n^2-1)-\log_e n} \times \frac{\text{bulk modulus}}{\text{mass per unit volume}}$$ where $1/n^2$ = ratio of cavity to total volume.

By putting the mass as the known mass of an electron and the bulk modulus twice the distortion modulus all the factors are known in terms of the ratio of volume of the cavity to total volume. The size of the cavity can then be ascertained from the Bohr atom as shown later.

Questions of symmetry will largely determine the mental picture of a Universe of ether columnar vortices in a compressible fluid. Through this universe in every direction there run circular holes exceedingly small in diameter and very close together. This fluid from other considerations probably is relatively very open or fragmentary but the groupings of its parts would be maintained constantly in equilibrium by the very high amount of the directing surfaces of the holes and the special nature of the sub- or ultimate atoms or its internal motions must otherwise be saturated or absorption of energy would take place. The extent of the surface per unit volume is so considerable that one cubic centimetre of ether probably contains within it several square miles of surface. In such an ether free from physical matter straightness of the vortices is secured by gyrostatic action. Thus in the immensities we get a universe not only true to the concept of Euclid, Galileo and Newton but also actually so divided up and marked out definitely and generally immoveable except for local distortions. Light and a variety of other signals are transmitted along the void places being propagated by lateral displacement. The void cavities are positive and negative, that is to say—for every spinning filament in one direction there must be another spinning in the opposite direction. Every direction in space is equally represented or the ether would show different properties in different directions. In dealing with the mechanical picture of such a universe it becomes difficult to

draw. But most of the mathematical requirements are met by assuming the columns to be collected together in the three co-ordinate planes making up a system of Cartesian co-ordinates. Such a system is indicated in Figure 3 which represents a block of ether with the void places running through it, the whole magnified

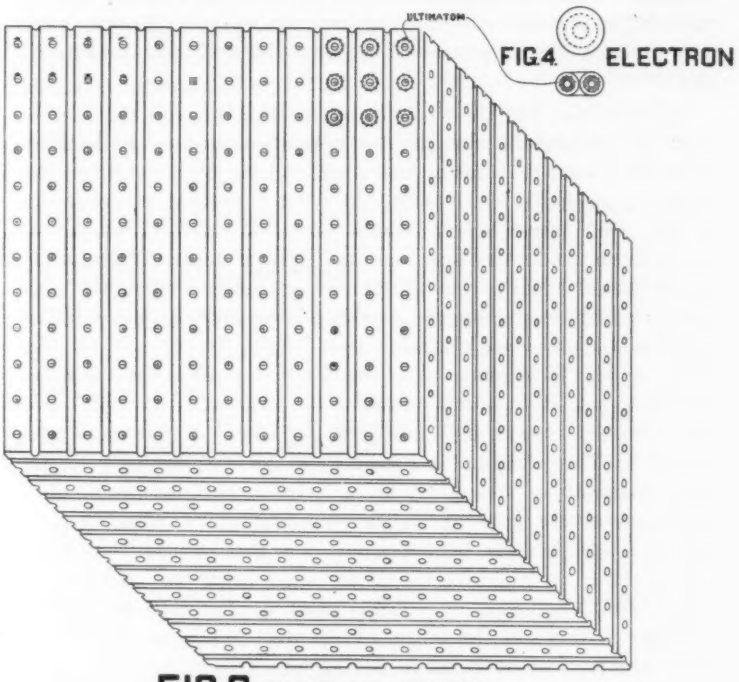

FIG. 3. CUBE OF ETHER

hundreds of million-million times, each direction and sense is equally represented. Each positive void place is surrounded by four negative ones which repel each other but each is enmeshed in the general whole from which it cannot escape and the motion at the surface of any one void place is the same as at any other. The spinning is eternal and remains indefinitely and forms a true

picture of uniform time and space. The material which spins must be regarded as made up of fragments having the character of little magnets. We call these ultimatoms. Whatever their exact nature may be they must be strung together much in the manner of beads on a string or the condition demanded by Maxwell could hardly be fulfilled. These ultimatoms and not the ether as a whole must be regarded as the seat of electro-magnetic forces in it. Further study may produce a better picture of the truth but it will serve to fix the ideas.

As the ether fills the whole of space—if we except the cavities, which in themselves must forever remain inviolate—any intrusion of another kind or form of substance such as we may picture the atoms of physical matter to be will cause a swelling or separation of the void places which would be very forcibly resisted by gyrostatic action and by mass inertia. That is to say,—the spinning action would tend to straighten out any distortion while mass inertia would resist changes in velocity sometimes acting with and sometimes against the gyrostatic action. Now, the atoms of physical matter appear to be made up of two kinds of bodies, the one called electrons and the other protons of hydrogen, in which the bulk of the mass and probably the volume of the atom resides. The electron is assumed to be made up of the same material as the ether as a whole, but the void place which forms the core of an electron instead of being straight and infinitely long is bent around into the form of a small ring as shown in Figure 4, the whole then being an anchor ring vortex with a hollow core probably much smaller than that of the columnar vortices in the ether. With such a scheme the motion within the electron is in entire equilibrium with that of the ether. The proton of hydrogen is taken to be a condensation of the electromagnetic substance of which the ether is composed. As in all atoms there is one electron to one hydrogen proton, except when ionization has taken place, the specific bulk of gross matter can be measured either by the bulk of the electrons or by the specific bulk of the atoms.

Figure 5 shows a cross section through a particle conveniently assumed to be spherical together with the field in which it exists.

This particle may be regarded as of any size whatever from an electron up to a star so long as the net volume is taken. Obviously physical matter is very porous. The original field undisturbed by the presence of the particle is shown by the faint squared co-ordinate lines and the strained field due to the presence of the particle by the firm lines. In spite of the fact that the swelling out of the field is very grossly exaggerated to 4 times the gross bulk of the spherical particle the strain produced very rapidly dies away with the distance and at a distance of a few times the diameter of

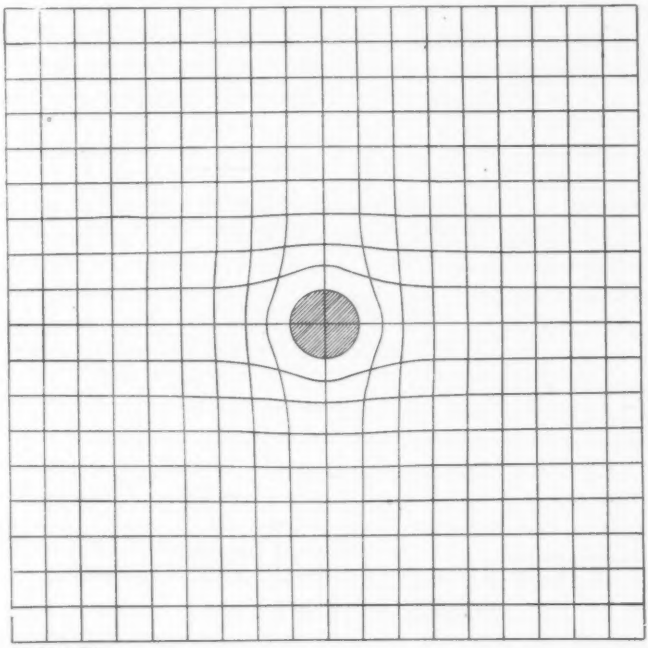

FIG 5. STRAIN IN SPACE DUE TO SINGLE BODY AT REST

the particle becomes too small to be shown on the diagram, but the effect is nevertheless there and can be determined by calculation. Except at points near or within the particle the radial strain follows

very nearly the law of inverse squares as shown by Figure 2, and by the equation

$$s = K[\sqrt[3]{R^3 + r^3CL} - R] = \frac{Kr^3CL}{3R^2}\left(1 - \frac{r^3C}{3R^3} + \frac{10}{5D}\frac{r^6C^2L^2}{R^6} - + -\right)$$

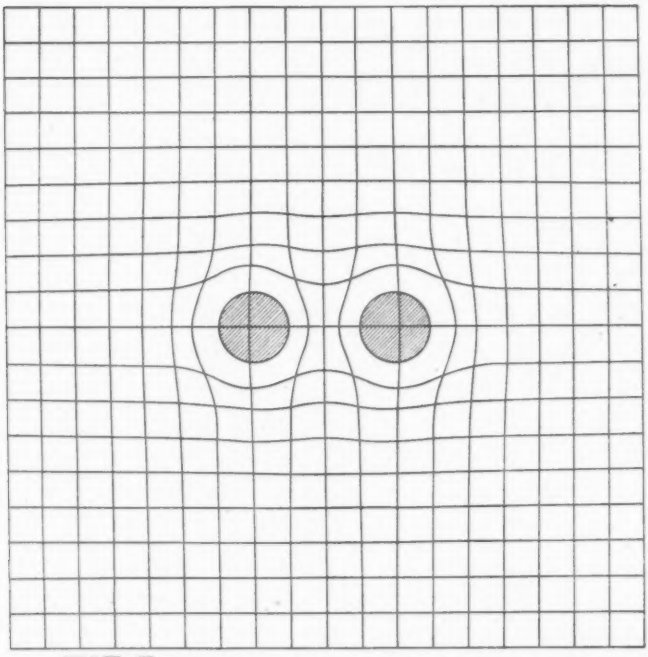

FIG. 6. STRAIN IN SPACE DUE TO TWO BODIES AT REST

Where S=radial strain

K=gravitational constant converts radial strain to gravitational potential estimated at about 4×10^{10} C.G.S. units

R=Radius from centre of particle to point considered

r=Radius of particle

C=The net specific volume of matter in the particle taking that of an electron as unity=$\frac{\text{Specific Gravity}}{6\times10^{7}}$

$\text{Log}_e L=\frac{KR}{D}$ is the logarithmic diminution of the total strain as the radial distance increases.

e=Base of the napierian logarithms

D=Bulk modulus of the ether estimated from the velocity of light and the specific mass of an electron.

The term within the brackets is very rapidly convergent so that for most astronomical problems the law is indistinguishable from that of Newton's and the strain may be expressed thus:

$$s=\frac{K\ C\ r^3\ L}{3\ R^2}$$

The factor L comes in by reason of the assumed compressibility of the ether. It becomes important when dealing with vast distances. If gravitation is due to strain then this factor has the effect of reducing the gravitational potential of the sun at the nearer fixed stars to one half that given by the Newtonian law. The importance of this lies in the effect upon the possible size of the universe. The Newtonian law leads to the conclusion that unless the field of stars we observe is limited in extent then the gravitational potential at any point becomes infinite which of course is impossible. The factor L sweeps away any such consideration and leads to a finite value well within bounds for the gravitational potential. It avoids the transcendental explanation of a universe with fifth degree constant curvature as introduced by Einstein. The law of inverse squares is shown in Figure 2 by the broken lines. Except at points quite close to the gravitating particle the strain curve is indistinguishable from it even although the diagram is grossly exaggerated in order to make a visible effect.

Obviously, if the particle moves a readjustment of the whole Universe takes place, but this cannot take place instantaneously and thus change in the strain is a progressive phenomena through space. Points near the particle readjust themselves immediately. Those

at a long distance away are a correspondingly long time before the adjustment takes place. At places an indefinite distance away the adjustment never takes place but then it is too small to mean anything. By the application of a similar principle to 3-dimensioned space and assuming the velocity of the adjustment to be the speed

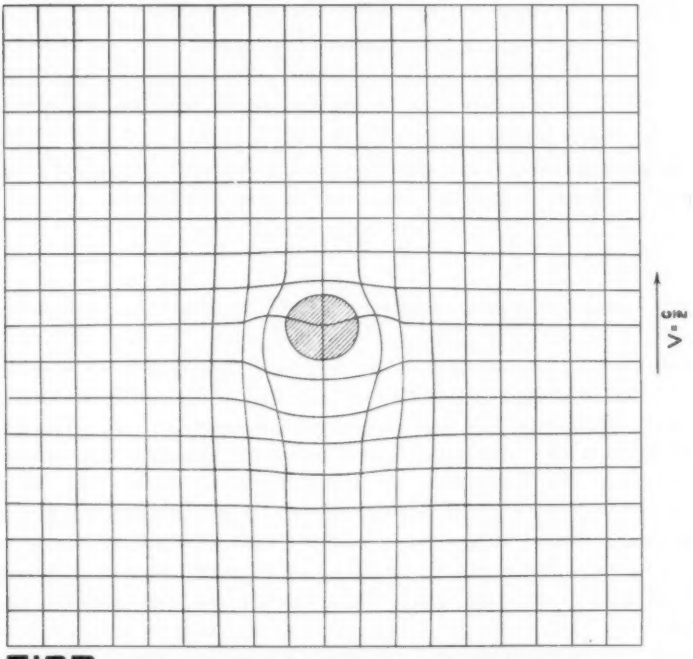

FIG.7. STRAIN IN SPACE DUE TO SINGLE BODY IN MOTION

of light Minkowski introduced the concept of the fourth dimension, imaginary time multiplied by the velocity of light being the other dimension. Einstein uses the same conception in his theory of relativity and the application of the theory of strain with progressive adjustments appears to yield much the same results as Einstein obtained except in some particulars.

In Figure 7 we have a cross section through the same particle as in Figure 5, but the particle is now moving upwards at half of the speed of light. The spherical body has now become oblate in accordance with the Fitzgerald contraction and the field has become unsymmetrical and unbalanced in the direction of motion. It indicates an increased strain behind the body and a reduced strain in front of it. This can only be balanced by forces acting upon the body of an impulse nature due to accelerated movements in the strain field represented by the equation.

$$\text{Pressure} = \text{Constant} \frac{\text{velocity of particle}}{\text{velocity of light}}$$

Undoubtedly there is an increased pressure upon the particle fore and aft and a reduction at its sides when it is in motion according to Bernouilli's principle, assuming the particle to be like a submarine travelling through water without frictional or wave resistance. Observations of an air bubble rising in water show clearly the contraction along the axis of motion and extension at right angles thereto. The Fitzgerald contraction is exactly satisfied if the particle and the field be in a state of stable equilibrium with an internal energy in both expressed in terms of the velocity of light. The balanced change in pressure due to acceleration of the strain field is of prime importance in considering the problem of a gravitating particle.

The accelerations in the strain field, reacting upon the particle, account for the so-called increase in mass as the velocity of a body increases.

Figure 6 shows a cross section through two particles, together with the field of strain produced by them. The same explanation of the lines applies to this case as in Figures 5 and 7. It will be seen that there is a considerable amount of unbalanced strain with resultants along a line joining the two particles together. That is to say,—the strain is largely cancelled between them and increased outside them along the line joining them together. From the extent of the distortion it is easily seen how these two bodies are forced together. The one shields the other from the forces generated by its own bulk intrusion into the ether. Thus, we have gravitation as a *real* force corresponding with the usual common

idea and not in accordance with that of Einstein, although there is a distorted gravitational field.

The distorted filaments press in on every side something like a jelly would press in upon a number of marbles squeezed into the middle of it if the idea is not carried too far. In this way the gravitational force at a given point would be directly proportional to the bulk of matter producing it, and not to its mass.

As we have seen, general considerations lead to the presumption that the velocities of the substance at the surfaces of the cavities are the same as that of light and as the density of the ether is very high compared with that of water the pressures within the interspaces are something prodigious. But this pressure is slightly increased by the presence of gross matter and the pressure is greater the closer it is packed together because of the greater distortion. The field of stars behind a large body like the sun will appear to expand by reason of the increased length of path the light rays have to travel which turns inwards the forefront of the waves and they converge in accordance with Einstein's prediction. To a lesser extent there are distortions in every direction. Thus there should be a small contraction in the field of stars opposite to the position of the sun.

The explanation of the cause of the acceleration of the perihelion passage of the planet Mercury is easily seen by the strain and ether mass inertia theory from the diagram Figure 8 which shows a small particle gravitating around a very large one at a very high velocity. It is well understood that if the falling off of the gravitational potential is greater than the inverse square, then the perihelion passage accelerates and therefore if it can be shown that the gravitational force is increased above the inverse square laws as the velocity increases which does take place as gravitating particles approach each other then the fact is proved. The diagram was originally drawn on squared paper such that a gravitational impulse travelling outwards at the uniform speed of light passes one square per second. At the same time the particle travels the distance of half a square from small circle to small circle along the approximately circular path and the successive adjustment waves are shown by the wave circles which crowd upon

each other in the direction of motion just as the ripples would form when caused by the sounding line of a ship in motion. In this respect it differs entirely from Einstein in which the wave front is at every point held to be a circle with the particle at its centre.

We proceed to find the gravitational strain produced at the

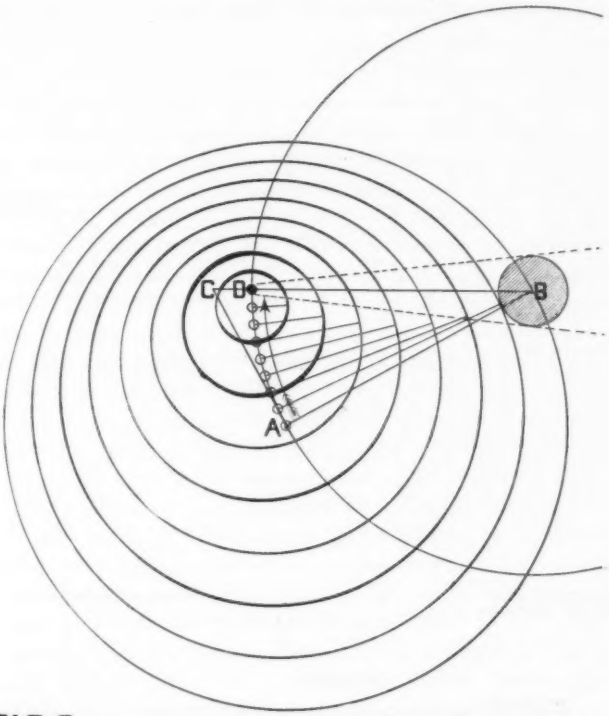

FIG. 8. SHOWING FIELD OF GRAVITATING PARTICLE

large body by the effect of the strain of the small one. This will be precisely the same as the effect of the strain of the large one upon the small. When the particle is at "A" a steady continuous adjustment is sent outwards which travels radially. The front of the adjustment waves is dead beat in the form of circles one of

which travels in 8 seconds to the large body at "B". At the same time the small body has reached the point "D". If the strain sent out from the particle at "A" is radial, then when it reaches the large body at "B" the strain and consequent gravitational impulse would not be along the line "B-D", but along the line "A-B", and if this were all the principle of the conservation of energy would be defeated. The actual gravitational force must have a resultant along

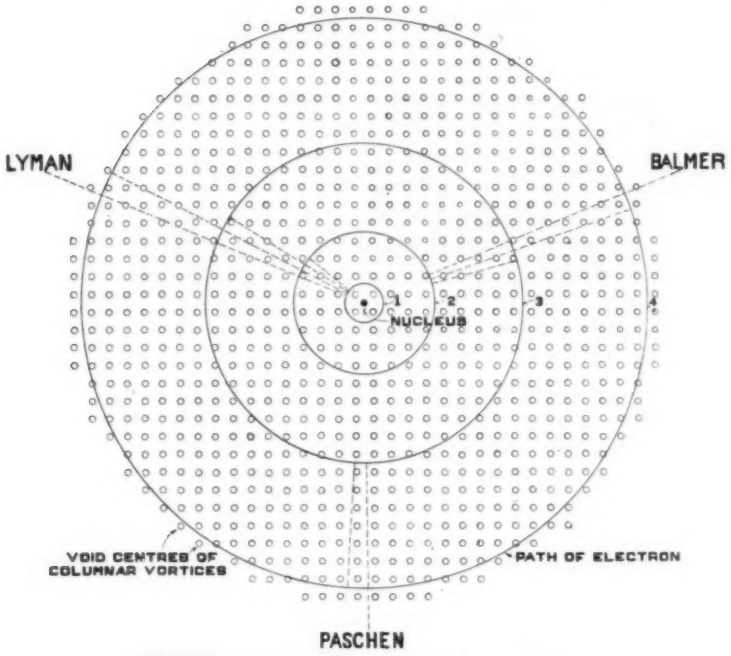

FIG.9. BOHR'S HYDROGEN ATOM

the line "B-D". It is due to a radial reaction along the line "A-B" and a tangential mass inertia reaction along "A-C" the resultant of which is "C-D" which is greater than that along "A-B" in the proportions of $1/\sqrt{1-\frac{v^2}{c^2}}$ to 1 when v, the speed of the particle, is small compared with c, the speed of light,—that is, when the arc

"A-D" differs little enough in length from the tangent "A-C" and the gravitational force is therefore greater, the greater the velocity of motion of the particle, which accounts for the acceleration of the perihelion passage of a rapidly gravitating body.

Figure 9 shows the application of the columnar vortex theory to the Bohr hydrogen atom with the three known series of emission lines described under the proper names of Lyman, Balmer and Paschen. The single electron of the hydrogen atom is rotating in one of the circular paths in one of the 3 co-ordinate planes in which the vortices lie, which is the simplest possible assumption for the vortex pattern. The small circles indicate cross sections of the void places at the centre of each vortex. The hydrogen proton at the centres of the picture is for the purpose of the diagram assumed to be at rest. In any event its motion is very small compared with that of the electron and no hiatus is introduced by assuming the proton in a condition of rest. The circular paths along any one of which the electron can travel, marked 1, 2, 3, 4, 5, etc., are at successive distances 1^2, 2^2, 3^2, 4^2, 5^2, etc., corresponding to the successive distances in the Bohr atom. Of any circular paths which can be drawn around the proton the only ones which avoid striking void places are those marked 1, 2 and 3, while the remaining paths, 4, 5, 6, etc., are remarkably more free from fouls than are any intermediate paths. Thus we have paths 1, 2 and 3 quite free from obstruction and the remaining paths represented by distances increasing as the square of successive integers partially so. Occasional hits will take place due in part to the motion of the proton. The electron under the influence of a central electrical attraction, whatever that may mean, gains velocity by falling inwards but the increase in the kinetic energy is twice as great as is necessary for stability in a new stable position and this causes it to foul again and again until the stable path and proper motion is arrived at. The surplus energy appears as radiation. The process is naturally reversible for when a disturbance which is dead beat comes from another source travelling along a void place hits an electron it gives it an impulse to which are added others until sufficient energy is absorbed to counteract the work done against the central attraction and leave sufficient motion for stability in a new path.

This investigation leads to the determination of the distance apart of the void places which is approximately 5.5×10^{-9} centimetres and the diameters about 1.8×10^{-9} centimetres while the diameter of an electron is about 3.75×10^{-13}.

A difficulty which presents itself is the pattern of the vortex filaments with their void centres. In its simplest form in three coordinate planes the conditions satisfy the Planck's Quantum and Bohr Atom Theories but the general experience of radiation would appear to demand that all directions should be equally represented but it is anticipated that further studies will remove this difficulty. It is also hoped to determine directly the actual mass of the ether by equating the gyrostatic reactions against the known gravitational forces. The subject is a difficult one and takes a lot of time and thought to develop it and it is hoped that the effort so far has not been in vain.

Toronto, Canada.

CORRECTIONS TO A LIST OF SPECTROSCOPIC BINARIES

By H. H. PLASKETT

SHORTLY after the completion and preparation for publication of the first radial velocity programme of the Observatory, a list of eighty-eight spectroscopic binaries[1] discovered during the course of that work was prepared. Owing to the pressure of other more interesting work, the measures and reductions of the stars in this list for which the writer was responsible were not checked with the same care as the constant velocity stars. This was regrettable, for while it is highly improbable that errors will so combine as to produce an apparent constant velocity for a star of variable radial velocity, a single error in either reduction or measurement in a star of constant velocity will result in an apparent spectroscopic binary.

The discovery by Mr. Stanley Smith of the University of Alberta, who is at the Observatory for the summer, of two slips in reduction in the star Boss 5126 has led me to check over the thirty-seven stars whose binary character I announced in the Observatory publication mentioned. In the case of each star the reduction to the sun, including the determination of λ and β, has been checked: in addition 49 spectra have been re-measured and 10 additional spectra have been secured and measured. For the majority of the stars this revision has resulted only in a few changes in velocity of individual spectra which do not affect the undoubted binary character of the star and which, since in addition the correction amounts in the majority of cases only to a few kilometres, there is no need to publish separately. Four of the stars, however, I would now regard as of constant velocity, and the names of the stars, their co-ordinates for 1900, and details of the measures are given in the following table; velocities with an asterisk are the mean of two or more measures. Notes on each star are appended to the table.

[1]Publications of the Dominion Astrophysical Observatory, Vol. I, No. 26.

Star: α, δ(1900)	Type Mag.	Date G.M.T.	Rad. Vel.	Lines	Quality
Boss 37	B9	1919 Aug. 20.975	0*	3	Good
00h 10.6m	6.23	Nov. 7.743	−12*	3	"
+76° 24′		1920 Aug. 7.955	−19*	2	Fair
		Oct. 13.842	−14*	2	"
		Nov. 7.746	−11*	2	Good
		1921 Jan. 22.586	0*	2	Fair
			−9.3±2.4		
Boss 348	A5	1919 Aug. 15.007	+ 9.3	6	Good
01h 30.5m	5.88	Oct. 29.816	0.0	5	"
+16° 55′		1920 Aug. 21.998	+ 2.0	3	Poor
		Sept. 5.890	+13.3*	4	Fair
		Oct. 18.857	− 0.3*	7	Good
			+4.9±2.2		
Boss 3011	FO	1920 Feb. 10.934	−6.6*	9	Fair
11h 20.7m	6.36.	Feb. 23.925	−9.0*	7	"
+04° 25′		April 24.760	+0.2*	8	"
		May 6.724	+3.5*	9	"
		May 23.703	−8.6*	10	Good
			−4.1±2.0		
Boss 5126	A2	1919 Oct. 17.618	+10.5*	11	Good
19h 56.2m	5.80	1920 July 6.873	+ 4.4*	6	"
+45° 30′		July 31.885	+ 4.1*	12	"
		Aug. 21.769	− 3.3*	4	Poor
		Sept. 16.788	+ 8.8*	7	Good
		1922 July 1.910	+ 7.8*	12	"
			+5.4±1.4		

Boss 37. While the velocity range in this star is large, it is no greater than the range in two measures of the same plate. At best only H_δ, H_γ and 4481 can be measured in the spectrum and and are very broad and diffuse.

Boss 348. This star was originally included as a binary owing to an error in reduction for the spectrum of October 18, 1920. The spectrum contains many weak, diffuse lines which are difficult to measure and this accounts for the somewhat large range.

Boss 3011. This spectrum has a number of very faint and

very diffuse lines. The velocity as originally published depended only upon some three or four of the stronger, better defined lines. All the plates have been remeasured using 9 to 12 lines. The velocities in the table are the weighted means of the two sets of measures, weight unity being given to the first measure with few, weight two to the second measure with more lines.

Boss 5126. This is the star in which Stanley Smith discovered two errors in reduction. When these were corrected it was clear the star was not a binary. The published velocities are the mean of his and my measures. The only discrepant velocity, that of August 21, 1920, is given by a very weak plate.

Victoria, B.C.,
August 6, 1924.

NOTES AND QUERIES

Communications are Invited, Especially from Amateurs. The Editor will try to Secure Answers to Queries

THE NORTHERN LIGHTS

By W. H. BARRACLOUGH in *The Toronto Globe*

The Tinne Indians of the Yukon have a legend that the Northern Lights are the spirits of their ancestors engaged in battle with an ancient foe.

This weird idea gathers support from the appearance of a wildly dancing host, the flash of changing colours, and a swishing, whistling sound, a babel of voices in the sky.

The description is of a display of Aurora Borealis seen at Dawson City in the winter of 1902.

Marching across the intervening space
  Between the mountain yonder and the hills,
  Light in weird lines the arching heaven fills,
Like ghostly legions of a vanished race.
Marshalled, they seem, for battle 'gainst their foes,
  Their many tinted banners clearly seen,—
  Crimson and yellow fading into green,—
Bravely defying all who dare oppose.
The spears flash forth and keen blades rend the sky,
  And now and then the whispers of command
We seem to hear,—a distant battle-cry,—
  Calling the ranks to close and make a stand.
  The battle ends amid a blaze of light,
  That fills with magic the long Arctic night.

Lindsay, Ontario.

THE HISTORY OF SCIENCE SOCIETY

There seems to be no end to the organization of new societies. There is an ever-widening gap between the various branches of science and much more so between science and letters, and the cultivation of the history of science seems to be about the only way to keep up a common bond between the workers in the different spheres of knowledge.

That there is room for the new society is shown by the fact that

although it was formed only last January it has a foundation membership of over 450. One reason for its existence is to assure permanency and adequate support to the international publication *Isis*, a periodical devoted to the history of science in its broadest aspect. It has been published for the past few years by its editor, Dr. George Sarton, under great difficulties.

The subscription price is six dollars but the annual dues of the Society are only five dollars and the publication will be sent free to members. By helping in the work of the Society the members will aid in maintaining and in assuring the future of a journal which is recognized as a powerful factor in stimulating the study of the history of science.

The secretary is Prof. David Eugene Smith, of Columbia University; and the treasurer and assistant secretary is Frederick E. Brasch, whose address is Department of Terrestrial Magnetism, Carnegie Institution, Washington, D.C.

THE BRITISH ASSOCIATION MEETING IN TORONTO

The recent meeting of the British Association for the Advancement of Science, held August 6 to 13, was a decided success. Indeed Toronto is becoming famous as a centre for large gatherings. As examples, we may refer to the International Rotary Convention in June which brought 6,000 or 7,000 visitors. Also the Canadian National Exhibition, which takes place for two weeks at the end of August and the beginning of September, has each year an attendance of well over a million. Another noted meeting this year was that of the International Mathematical Congress, which was held from August 11 to 16. It brought to Canada a large number of distinguished foreign visitors.

Section A of the British Association includes Mathematics, Physics, Astronomy, Meteorology and Seismology; and consequently its programme was an extended one. There were no purely mathematical papers presented. The physicists were very active, their chief subject of discussion being the nature of the atom. In astronomy Prof. A. S. Eddington, of Cambridge, gave a paper on "Theory of the Outflow of Radiation from a Star", and also a public lecture on "Relativity" which was delivered to an audience of about 1,600 and at the same time was broadcasted to thousands

more. I shall give the titles of other papers: H. H. Plaskett, Victoria, "The Spectra of the Nebulae"; J. Jackson, Royal Observatory, Greenwich, "Photographic Proper Motions of Faint Stars"; R. K. Young and W. E. Harper, Victoria, "Methods and Results of Spectroscopic Absolute Magnitude Determinations"; F. Henroteau, Ottawa, "The System of Sigma Scorpii"; Rev. A. L. Cortie, Stonyhurst College, Eng., "The Relation between Solar Activity and Terrestrial Magnetic Disturbance"; R. Meldrum Stewart and J. P. Henderson, Ottawa, "Wireless Time Signals"; F. J. W. Whipple, British Meteorological Office, "An Experiment Illustrating the Theory of the Green Flash" and "The Diurnal Variation of Pressure: Facts and Theories"; Sir Napier Shaw, formerly director of the British Meteorological Office, "If the Earth went Dry"; J. S. Owens, London, Eng., "The Automatic Measurement of Atmospheric Pollution"; J. Bjerknes, "The Importance of Atmospheric Discontinuities for Practical and Theoretical Weather Forecasting"; L. F. Richardson, "Turbulence and Temperature-gradient among Trees"; H. Jeffreys, "Tidal Friction"; L. Silberstein, "Determination of the Curvature Radius of Space-Time".

Three distinguished members of the United States Weather Bureau were present, namely, Prof. C. F. Marvin, Chief of the Bureau, who spoke on "Let us Simplify the Calendar and Publish Statistical Data in Standardized Summaries"; Prof. H. H. Kimball who discussed "The Determination of Daylight Intensity from Automatic Records of Total Solar and Sky Radiation"; and Prof. W. J. Humphreys, who presented papers on "The Relation of Wind to Height" and "Rainmaking".

Seismology was represented on the programme by E. A. Hodgson, of Ottawa, who read a paper on "Correlation of Records of two Distant Milne-Shaw Seismographs", and J. J. Shaw, of London, Eng., who presented the "Report of the Seismology Committee".

C. A. C.

The Royal Astronomical Society of Canada

(OFFICERS FOR 1924—REVISED TO MARCH 1ST, 1924)

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